

# ARCHITECTURAL STUDY OF ACTIVE MEMBRANE ANTENNAS

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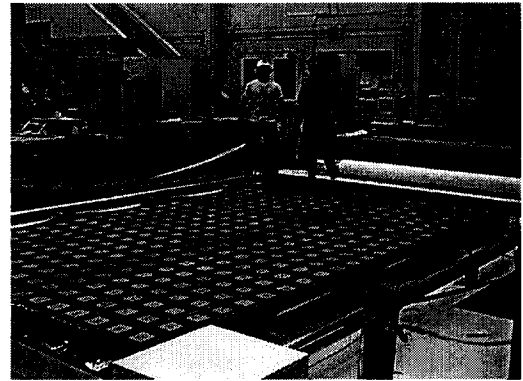
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## ABSTRACT

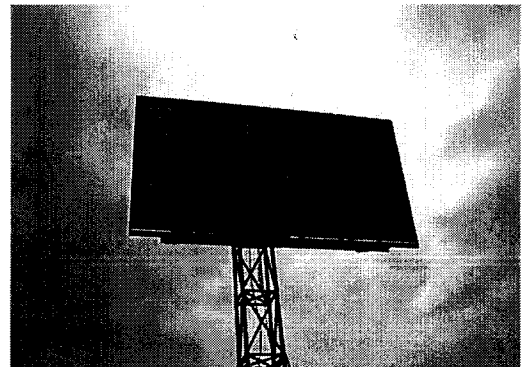
One method to dramatically reduce the weight, volume and associated cost of space-based Synthetic Aperture Radars (SAR) is to replace the conventional rigid manifold antenna architecture with a flexible thin-film membrane. This has been successfully demonstrated as a passive array. To further reduce the cost and weight and provide 2D scanning required by space-based applications we also need to integrate the Transmit/Receive (T/R) function into the inflatable antenna elements. This paper explores the constraints that must be placed on the active electronics of a flexible antenna array as well as some of the preliminary work in this area.

## INTRODUCTION

Conventional phased-array antenna design and manufacturing processes will not meet the performance and cost goals of future space-based SARs. Current systems are designed using modular architectures where electronic components are individually packaged and integrated onto rigid manifolds or panels. With membrane antenna technology, an order-of-magnitude reduction in antenna mass density can be achieved. JPL has recently demonstrated a 3mx5m microstrip patch antenna prototype where multiple layers of stretched membranes are supported by a space-inflatable planar frame structure (Figure 1a). JPL has also demonstrated a similar membrane antenna supported by a lightweight composite frame (Figure 1b) [1-3]. Both of these antennas have demonstrated mass densities less than  $2 \text{ kg/m}^2$  which include structure, aperture and electronics. The measured performance of these antennas include 80MHz bandwidth at L-band, dual-linear polarization, 74% aperture efficiency, and a fixed beam at boresight. Flexible membrane antennas could further revolutionize space-based SARs if they were capable of 2-D electronic beam scanning. By developing membrane compatible electronics and manufacturing techniques,



(a)



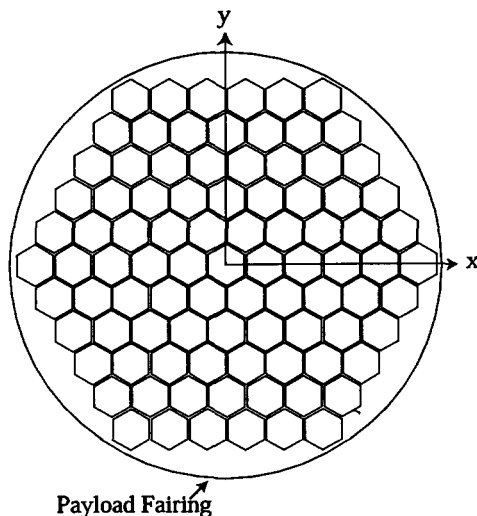
(b)

**Figure 1. L-band 3mx5m (a) Inflatable Membrane Antenna. (b) Framed Membrane Antenna.**

ultra-lightweight, large aperture antennas with large scanning angles in azimuth and elevation would be enabled. This will not only result in cost saving for future missions but also by allowing larger antennas new missions such as the geosynchronous SAR mission for tectonic mapping and disaster management will be possible [4,5].

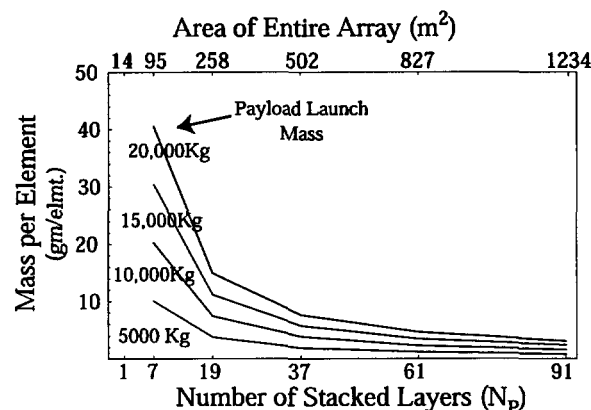
## ANTENNA ELEMENT MASS LIMITATION

The goal of this section is to demonstrate the mass requirement for each antenna element in a very large



**Figure 2.** A hexagonal distribution of antenna elements in the payload of a launch vehicle. Many layers can be stacked on top of each other.

array. To simplify this calculation we assume that instead of a membrane antenna that is stowed in a rolled position, flexible panels or membranes are arranged in a flat form and stacked one on top of the other. Figure 2 shows the basic grid geometry of the flexible membrane and how it can fit within the payload bay of a launch vehicle. For simplicity we assume that the cross section of the payload bay is a circle and that the antenna elements are distributed in a hexagonal grid pattern. It is also assumed that the center of each cell is separated from its neighbor by half the wavelength of the operating frequency. For instance at a center frequency of 1GHz the separation is 15cm and at 10GHz it is 1.5cm. Using these assumptions it is possible to calculate the number of antenna elements per layer for different launch vehicles depending on the payload bay diameter of the spacecraft. Then by using the maximum allowable payload launch mass for each vehicle we can calculate the number of layers that can be stacked and thereby calculate the total antenna surface area possible. Figure 3 shows the calculated effective mass per element of an array as a function of the number of stacked panels (or array area) for the space shuttle at L-band. In addition to the mass of each antenna element and electronics the effective mass also includes the mechanical support structure, solar cells, panel reconfiguration motors, propulsion, etc. This explains why the effective mass per element in Figure 3 does not decrease linearly with increased antenna area. This calculation shows that for an L-band SAR with a total area of 500m<sup>2</sup> that is launched using the space shuttle the effective mass per element should be less than 10gr.



**Figure 3.** Effective mass per element as a function of the number of stacked layers (or array area). The Payload launch mass shows the maximum allowable launch mass for the space shuttle for different orbits.

### SYSTEM REQUIREMENTS

Besides the mass of the antenna elements discussed in the previous section the constraints placed on the satellite by a flexible membrane structure are many and these requirements directly impact the specifications of any in-situ electronics. The active system needs to be designed and integrated such as to minimize the impact on passive satellite array and the number of membrane layers. The T/R modules have to be packaged and attached using flex compatible technology. Moreover since the electronics is distributed on the antenna itself hermetic sealing of the electronics is essential. Due to the large number of active elements and the high data rates generated the RF, digital and power distribution becomes challenging and the heat dissipation from the modules needs to be taken into account [6]. Additionally, the ability of each antenna element to be easily manufactured, installed, diagnosed, and maintained in space is critical.

### SYSTEM ARCHITECTURE

The method of signal distribution on the array effects the system architecture. The signals routed to the T/R membrane can use transmission lines or can be routed remotely (wireless connection). As will be explained later the wireless idea although interesting complicates the architecture and does not seem to address the data handling requirement of future systems.

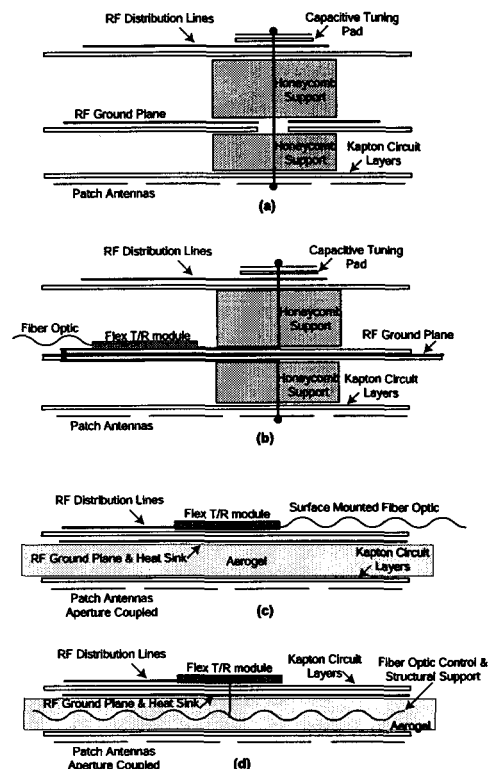
There are three types of signals located on the antenna: power, digital, and RF. Digital and RF signals can, in principle, be taken from a central location and transmitted by a transmission line to the T/R modules. Figure 4a shows the current passive

antenna architecture. The antenna consists of 3 Kapton™ membranes. The bottom membrane contains all the radiating patches, the middle membrane is the ground plane and the top membrane is for the power dividing lines [?]. Figures 4b-4d show a number of possible system architectures for the proposed first generation T/R membrane where only the control signals are carried through optical fiber. The RF inputs and outputs are through conventional RF transmission lines. The optical fiber must be jacketed with a material that will survive the space environment and will allow for easy attachment to the membrane. The fibers and jackets must have superior thermal properties and ideally, the fiber distribution system should not require another physical layer of flexible membrane material to route the optical fibers as this increases complexity, mass, cost, and layer alignment problems. Gold jacketed fibers have been chosen because they meet all of these requirements and open the possibility for routing DC power signals as well. Figures 4c and 4d show a proposed 2-layer structure. Instead of using the current honeycomb support it is conceivable to use high strength yet very lightweight materials, such as aerogels for supporting the structure and the fibers. Figure 5 shows the aerogel material. This material is based on silicon that is chemically prepared as to have a very porous form and has a density of less than 0.1gr/cm<sup>3</sup>. Due to its low mass and support ability aerogel could be used to support optical routing of satellite data bus as well as serve as a heat shield for critical electronics due to its extremely high thermal resistivity (give No.).

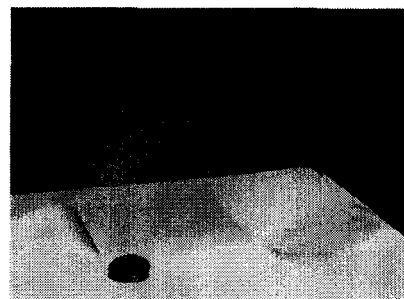
For future, more advanced systems a transmission line network where the lines can be shared for different purposes (control & data) is desired. This will reduce the wiring and distribution complexity, especially for apertures with potentially thousands of T/R membranes. Since some of future remote sensing applications require rather vast amounts of data (5-10 Gbit/s) to be moved around the satellite, only fiber optics offers this amount of bandwidth easily. This is yet another advantage of using optical fiber for the T/R membrane control.

#### Packaging and Attachment

The main difficulty in using fiber optics is in the packaging technologies that are required for creating a space-qualified system. Initially it was unclear that a fiber optic approach would be as useful as it now appears. The typical packaging for optical IC's is very time intensive and the yields are low. These conventional methods are obviously unacceptable for packaging and aligning thousands of T/R modules on



**Figure 4.** Cross Section of the current passive antenna (a). Possible system architectures for a 3-layer (b) or 2 layer (c & d) active membrane antennas with optical control.



**Figure 5.** Aerogel Material.

an array. One possible new solution to the connector interface challenge is based on a technology developed by Boeing. This new alignment technology is compatible with future integrated System on Silicon (SOS) approach to the T/R membrane design, where all of the RF, optical and digital components are placed on the same Si substrate. In this packaging approach after optical fibers are fed into the optical device package, they are attached to the In-Package MEMS Aligner (IPMA). The IPMA is a consumable, low-cost, active

device fabricated using standard MEMS semiconductor fabrication technology which enables hundreds of MEMS aligners to be produced per silicon wafer. Tiny, electrically-activated actuators are heated and cooled to expand and contract inside the hermetically sealed MEMS package, pushing and pulling the optical fibers into alignment with the optical device along the X,Y, and Z planes. Once alignment is achieved, the fiber is secured in place with solder preform (or an alternative bonding method, such as laser welding or adhesive bonding) and the actuators are turned off.

Attaching the hermitically sealed T/R module package onto the membrane could be accomplished using different technologies such as flip-chip bonding, epoxy, solder or inert gas welding techniques such as TIG.

## CONCLUSION

Very large SAR arrays are essential for future Earth Science and Space missions. Inflatable membrane antennas can make these missions possible. The membrane T/R module must be designed with the correct technology to handle each of the signal types: RF, digital, and power. The data transfer appears to best be handled by fiber optic link to handle the expected future bandwidth requirements. Finally, the integration of all the aspects of the flexible compatible T/R module, including packaging, must be done concurrently since the eventual satellites that will use them are very sensitive to mass, structures, and power constraints.

## ACKNOWLEDGEMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. This work was supported by NASA Code R, Enabling Concepts and Technologies Program-Advanced Measurements and Detection.

## REFERENCES

- [1] Huang, Lou, and Caro, "Super Low Mass Spaceborne SAR Array Concepts," presented at the *IEEE Antennas and Propagation Symposium*, Montreal, Canada, July 97.
- [2] Huang, Lou, Fera, and Kim, "An Inflatable L-Band Microstrip SAR Array," *IEEE AP-S/URSI Symposium*, Atlanta, GA, June 98, pp. 2100-2103.
- [3] Lou, Fera, Huang, "Development of An Inflatable Space SAR," presented at the *39th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conf.*, 1998.
- [4] S.N. Madsen, W. Edelstein, L.D. DiDomenico, and J. LaBrecque, "A Geosynchronous Synthetic Aperture Radar; for Tectonic Mapping, Disaster Management and Measurements of Vegetation and Soil Moisture," *IEEE Symposium on Geoscience and Remote Sensing*, IGARSS'01, pp. 447-449, 2001.
- [5] S.N. Madsen, C. Chen, and W. Edelstein, "Radar Options for Global Earthquake Monitoring," submitted to the *IEEE Symposium on Geoscience and Remote Sensing*, IGARSS'02
- [6] M. Celis, K.T. Lien, E. R. Brown, J. Huang, and W. Edelstein, Local Thermal Management for Space-Borne Inflatable RF Antennas, to be presented at the *ITherm 2002 Conference*, San Diego, CA.